

As it was frozen to the collar C, and therefore unable to expand upwards, since both collars were fixed to a frame, the cylindrical part of the ice bulged outwards, as in the usual case of a long column under compression. When the specimen was subsequently exposed to tension, the effect of the latter was to straighten it, so that in a few days it no longer bulged out. The straightening of the central line of the ice cylinder thus gave rise to greater extensions than were due simply to the extension of a straight bar of ice with an equal distance in all azimuths between the rings.

“The Air of Sewers.” By Professor THOMAS CARNELLEY, D.Sc., and J. S. HALDANE, M.A., M.B., University College, Dundee. Communicated by Sir H. ROSCOE, F.R.S. Received May 21.—Read June 16, 1887.

Owing to the complaints which had been made of bad smells in the House of Commons, a Select Committee was appointed in the spring of 1886 to inquire into the ventilation of the House. In consequence of the experience we had gained in the course of an extensive examination of the air of houses and schools in Dundee (see ‘Phil. Trans.,’ vol. 178 (1887), B, p. 61), we were instructed by the Committee to make a series of analyses of the air in the sewers under the Houses of Parliament, and to report thereon (see ‘Second Report of the Committee,’ Appendix). Since then we have examined the air in a considerable number of sewers in Dundee.

Our object was, in the first place, to obtain a general idea of the amount of some of the more important impurities present in sewer air. But we have also endeavoured to throw some light on their sources, and on the conditions affecting their dissemination. With this view we found it desirable to supplement our observations in the sewers by a certain number of laboratory experiments.

In spite of the great amount of discussion which has taken place in connexion with real and supposed danger from sewer air, there have hitherto been but few analyses published of the air of sewers of modern construction.

The first and most complete set of analyses was that made by Dr. Letheby in 1857–58 (‘Report to the City of London Commissioners of Sewers,’ 1858). He examined the air of thirteen sewers in the City of London. The following are the means of his analyses :—

Oxygen, per cent.	Nitrogen, per cent.	Vols. of carbonic acid per 10,000.	Marsh-gas and sulphuretted hydrogen.	Ammonia.	100 grains of air deprived of water and carbonic acid gave after oxidation.	
					Carbonic acid.	Water.
19·506	79·962	53·2	traces.	"Rather abundant."	1·247 grains.	1·126 grains.

Unfortunately no information is given as to the condition and means of ventilation of these sewers.

In 1867 Dr. Miller,\* in an investigation on the action of charcoal air filters, made a number of analyses in two London sewers. The first series was made in a clean and well-ventilated sewer, and the second in a sewer described as "tide-locked and ill-ventilated." In the first series (eighteen analyses) he found on an average 10·6 vols., and in the second (six analyses) 30·7 vols. of carbonic acid per 10,000 vols. of air. In neither series could sulphuretted hydrogen be detected, and in both series the ventilation was by means of open gratings.

In 1877 Beetz† in Munich found 31·4 vols. of carbonic acid, and 2·2 vols. of ammonia per 10,000 as an average of five analyses.

As regards the micro-organisms present in sewer air the only analyses hitherto published are those of Miquel.‡ He says, "The atmosphere of sewers, always saturated with moisture and constantly in contact with water more or less filthy and loaded with putrefying substances, is heavily charged with bacteria. Judging from a series of experiments made in the sewer of the Rue de Rivoli in the neighbourhood of the point at which this sewer joins the large collector of the Boulevard Sébastopol, there are present in the air circulating in this gallery 800 to 900 bacteria per cubic metre"§ (= 0·8 to 0·9 per litre). He also states that the air of the sewer contains an almost constant number of bacteria, and that in summer the air of the Rue de Rivoli may exceed in impurity by five or six times that of the sewer, while in winter the air of the sewer may be five or six times more impure. No details are furnished as to the condition and means of ventilation of the sewer, nor as to the number of analyses on which these conclusions are based.

\* 'Chemical News,' March 13th, 1868.

† Quoted by Erisman in Pettenkofer and Ziemssen's 'Handbuch der Hygiene,' vol. 2, p. 197.

‡ 'Les Organismes Vivants de l'Atmosphère,' 1883, p. 273.

§ These numbers refer to the bacteria capable of developing in a solution of Liebig's extract of 1·024 specific gravity placed in an incubator at 30°—35°.

Miflet ('Biedemann's Centralbl.,' 1880, p. 227) states that air taken from above a sink was rich in micro-organisms.

In detailing our own observations it may be as well, in the first place, to give some account of the sewers in which they were made. The main sewer of Westminster Palace,\* in which our first observations were made, ran along underneath the open courts in the centre of the building from the neighbourhood of the Victoria Tower to that of the Clock Tower, a short way beyond which it joined the main low-level metropolitan sewer. Along its course it varied irregularly in height from  $4\frac{1}{2}$  to  $10\frac{1}{2}$  feet. It was ventilated by suction from the large furnace at the foot of the Clock Tower, and was cut off by a penstock from the metropolitan sewer. The air drawn into the shaft of the furnace almost all came from openings near the Clock Tower end of the sewer. In the rest of the sewer there were no open gratings, and the draught was feeble. On opening the trap-door of a man-hole near the Victoria Tower there was an upward rush of air and condensed vapour, in spite of the very powerful suction at the other end of the sewer. The sewer was flushed daily. It was clean, and the flow of sewage was pretty rapid. The water frequently accumulated in the sewer during rain owing to rise of the level of the water in the metropolitan sewer. Our analyses were made when the water was escaping freely.

The second set of analyses at Westminster was made after the ventilation of the sewer had been altered by carrying an additional shaft to the furnace and placing inlet gratings in suitable positions. By this means the draught along the sewer from the neighbourhood of the Victoria Tower was much increased.

We owe the facilities which were afforded us for examining the air in the Dundee sewers to the courtesy of Mr. Mackison, Burgh Engineer. We met with a variety of conditions in these sewers. They are all ventilated by open gratings placed in the roadway at distances of about 50 yards apart, and also by the open drain grids placed along each side of the road at distances of about 40 yards. The flow of sewage was in almost every case pretty rapid at the time when our analyses were made. The sewers in Commercial Street, Overgate, and Nethergate are egg-shaped; that in Murraygate is a large circular sewer. Those in Reform Street and Dock Street had originally been large, old, flat-bottomed stone sewers, but had been partially altered by the substitution of a bottom similar to that of an egg-shaped sewer. The Dock Street sewer is alternately filled and emptied by the tide, as is also the sewer in Commercial Street, opposite Exchange Street. The approximate heights of the several sewers are

\* This sewer has now (1887) been replaced by a pipe, on the recommendation of the Select Committee.

## A. Main Sewer under Houses of Parliament.

Date and place.	Time.	Approximate height of sewer.	Temp. F.	Vols. CO <sub>2</sub> per 10,000 vols. of air.	Vols. of oxygen required to oxidise the organic matter in 1,000,000 vols. of air.	Total No. of micro-organisms per litre of air.
April 19th-20th, before alterations.						
First series :—		feet.				
In sewer near Victoria Tower .....	5.0 P.M.	4½	55°	8.9	9.5	1 (0)
Ditto near kitchen .....	6.0 "	7	59	8.6	12.9	2 (1)
Ditto near Clock Tower .....	7.30 "	4½	56	7.6	12.8	13* (0)
Outside air in centre of court, near old Crown Office .....	8.30 "	..	51	4.2	3.1	9.2* (—)
Second series :—						
In sewer near Victoria Tower .....	10.30 "	4½	52	8.8	9.5	2 (0)
Ditto near kitchen .....	11.15 "	7½	56	7.3	9.5	5 (0)
Ditto near Clock Tower .....	12 midnight	4½	52	5.4	11.9	19 (3)
Outside air at same place as before .....	1.0 A.M.	..	47	..	..	4* (0.4)
May 18th-19th, after alterations.						
Third series :—						
In sewer near Victoria Tower .....	5.0 P.M.	4½	56	7.3	5.4	4 (1)
Ditto near kitchen .....	5.20 "	7	58.5	5.9	3.2	8 (4)
Ditto near Speaker's Court .....	7.10 "	10½	..	6.2	3.1	..
Ditto near Clock Tower .....	7.20 "	4½	57	..	3.2	38 (1)
Outside air, at fresh air inlet to sewer .....	6.0 "	..	59	4.3	2.5	18 (4)

A. Main Sewer under Houses of Parliament—continued.

Date and place.	Time.	Approximate height of sewer.	Temp. F.	Vols. CO <sub>2</sub> per 10,000 vols. of air.	Vols. of oxygen required to oxidise the organic matter in 1,000,000 vols. of air.	Total No. of micro-organisms per litre of air.
Fourth series :—		feet.				
In sewer near Victoria Tower.....	11.0 P.M.	4½	56°	6.7	1.0	0.5 (0)
Ditto near kitchen.....	11.40 "	7	59.5	4.9	1.6	2 (1)
Ditto, near Speaker's Court.....	1.15 A.M.	10½	..	6.7	Too small to estimate.	
Ditto near Clock Tower.....	1.30 "	4½	56	5.8	1.7	8 (2)
Outside air at fresh air inlet to sewer.....	12.30 "	..	47	4.5	Too small to estimate.	3 (1.5)

B. Dundee Sewers.

		feet.				
April 27th, under Commercial Street.						
In sewer between Murraygate and Seagate.....	4.15 P.M.	4½	49	6.7	6.5	5 (2)
Ditto.....	5.15 "	4½	49	8.8	12.7	4 (0.5)
In sewer opposite Exchange Street.....	6.30 "	3	49	7.6	7.5	2.5 (1)
Outside air in open yard, Commercial Street.....	5.45 "	..	..	3.9	3.2	4.4 (1)
April 29th, under Murraygate and High Street.						
In sewer near entrance of Hill Town Sewer.....	3.30 "	5½	..	5.5	6.5	3 (0)
Ditto near Meadow entry.....	5.30 "	5	..	10.2	9.4	
Ditto near Pillars.....	4.45 "	5	52	7.4	9.5	
Outside air in open yard, Commercial Street.....	5.15 "	..	45	3.0	1.6	5 (0.2)

B. Dundee Sewers—*continued*.

Date and place.	Time.	Approximate height of sewer.	Temp. F.	Vols. CO <sub>2</sub> per 10,000 vols. of air.	Vols. of oxygen required to oxidise the organic matter in 1,000,000 vols. of air.	Total No. of micro-organisms per litre of air.
May 7th.						
In sewer under Overage.....	4.15 P.M.	feet. 3.5	53°	8.6	18.2	13 (3)
Ditto under Reform Street, High Street end .....	5.0 "	7	52	7.4	7.6	14.5 (0.5)
Ditto, ditto, Albert Square end.....	6.0 "	7	54	10.8	6.7	4 (0)
Ditto under Nethergate.....	7.30 "	4	..	10.9	6.4	25 (1)
Outside air in open yard, Commercial Street.....	6.30 "	..	..	3.0	2.2	16 (1.2)
May 11th, under Dock Street.						
In sewer near Sailors' Home .....	2.50 "	9	52	7.9	3.1	6 (0)
Ditto east of entrance to Commercial Street.....	3.50 "	7	53	6.1	9.6	[103 (0)]†
Ditto opposite entrance to Commercial Street.....	4.15 "	7	..	5.5	3.8	12 (2)
Ditto near foot of Union Street.....	5.0 "	5	49	9.4	9.1	12 (2)
Outside air in yard off Dock Street.....	4.30 "	..	46	3.1	3.1	60 (-)

The figures in brackets placed beside the figures for total micro-organisms refer to the number of moulds per litre.

\* An asterisk signifies that owing to running together of the colonies in the Hesse's tube the total number of micro-organisms could not be found correctly. The true number must have been larger than that actually given.

† Not included in the averages, as the highness of the number was due to exceptional circumstances (see below).

	Total.				In excess of outside air at time.			
	Temp. F.	Vols. carbonic acid per 10,000 vols. of air.	Vols. oxygen to oxidise the organic matter in 1,000,000 vols. of air.	No. of micro-organisms per litre.	Temp. F.	Vols. carbonic acid per 10,000 vols. of air.	Vols. oxygen to oxidise the organic matter in 1,000,000 vols. of air.	No. of micro-organisms per litre.
April 19th to May 19th, 1886.	54°	7·5	7·2	8·9	5·2°	3·8	4·9	—7
	49	3·7	2·2	15·9	..	..	..	..
Houses :— One-roomed..... Two-roomed..... Four rooms and upwards. Nov. 28th, 1885, to end of April, 1886.	55	11·2	15·7	60	19	6·6	6·2	60
	53·5	9·9	10·1	46	18	5·5	2·2	46
	54·5	7·7	4·5	9	14	3·3	1·4	9
Schools :— Naturally ventilated.... Mechanically ventilated..	55·6	18·6	16·2	152	16·8	15·1	7·8	152
	62	12·3	10·1	16·5	24	8·9	1·1	16·5

given in the table of results (pp. 504—507). It will be seen that the sewers which we examined were all of considerable size, large enough to be entered without great difficulty. Our data, therefore, do not apply to small sewers and drains.

In each sewer examined we estimated simultaneously the amounts of carbonic acid, "organic matter," and micro-organisms, as in the case of our observations referred to above on the air of houses and schools. Analyses of outside air in the immediate vicinity of the sewers examined were made at as nearly as possible the same time. In order to avoid as far as possible contaminations due to our own presence we kept to leeward of the apparatus employed in collecting the samples. The methods employed were that of Pettenkofer for carbonic acid, Carnelley and Mackie's modification of the permanganate process for organic matter,\* and Hesse's method for micro-organisms.† The results obtained are given in the preceding table.

For the purpose of giving a general idea of the relative impurity of sewer air we have taken the averages of analyses A and B of sewer air and placed them alongside of the averages for outside air at the same time, and for various classes of houses and schools, as determined by us in the winter of 1885–86 and detailed in the paper mentioned above.

The above table shows (1) that the air of the sewers was much better than one might have expected; (2) that the carbonic acid was about twice, and the organic matter rather over three times as great as in outside air at the same time, whereas the number of micro-organisms was less; (3) that in reference to the *quantity* of the three constituents named, the air of the sewers was in a very much better condition than that of naturally ventilated schools, and that with the notable exception of organic matter it had likewise the advantage of mechanically ventilated schools; (4) that the sewer air contained a much smaller number of micro-organisms than any class of house. The carbonic acid was rather greater than in the air of houses of four rooms and upwards, but less than in two- and one-roomed houses. As regards organic matter, however, the sewer air was only slightly better than the air of one-roomed houses, and much worse than that of the other classes of house.‡ These facts are brought out more clearly in the following table, in which the average quantity in excess of outside air of each constituent in sewer air is taken as unity.

\* 'Roy. Soc. Proc.,' vol. 41, p. 238.

† 'Mittheilungen aus dem k. Gesundheitsamte,' vol. 2, p. 182.

‡ The data for all the classes of houses refer to sleeping-rooms when occupied during the night.



	Carbonic acid.	Organic matter.	Micro-organisms.*
Sewers.....	1	1	1
Houses { one-roomed.....	1·7	1·3	7 <i>x</i>
{ two-roomed.....	1·4	0·45	5 <i>x</i>
{ four rooms and upwards .	0·9	0·3	<i>x</i>
Schools { naturally ventilated.....	4·0	1·6	17 <i>x</i>
{ mechanically ventilated ..	2·3	0·2	2 <i>x</i>

On comparing the average amount of carbonic acid found by us in sewer air with that found by earlier investigators (see above), it appears that the sewers we examined must have been much better ventilated than those previously examined.

In our paper on the air of schools and houses, we pointed out that in individual cases the amount of carbonic acid is not a measure of the amount of the organic matter and number of micro-organisms present in the air at the same time; and that it is only when the average of a comparatively large number of cases is taken that the organic matter is seen to increase with the carbonic acid, while the micro-organisms show no evident connexion with the carbonic acid and organic matter. In the air of sewers the relation to one another of carbonic acid and organic matter is similar. The micro-organisms on the whole decrease as the other constituents increase. This is shown in the following table, in which the organic matter and micro-organisms are compared in amount with the carbonic acid as a standard. The table is constructed by dividing all the carbonic acid determinations into three equal groups according to the amounts of carbonic acid found, and then taking the average of the corresponding organic matter and micro-organism determinations in each group.

	Temperature.	Carbonic acid.	Organic matter.	Micro-organisms.
Total :—				
4·9— 6·2 vols. carbonic acid.....	55·8°	5·7	5·1	8·7
6·7— 7·9       "       "       .....	53·1	7·3	6·3	6·4
8·6—10·9       "       "       .....	53·0	9·4	10·5	5·4

\* In this case we have represented the relation of the number for sewer air to that for air in four-roomed houses by *x*, as the calculated number for sewer air is negative. The real value of *x* must be between  $\frac{2}{3}$  (= 1·3) and infinity.

	Tempe- rature.	Carbonic acid.	Organic matter.	Micro- organisms.
In excess of outside air at same time :—				
0·4—2·5 vols. carbonic acid.....	7·0°	1·76	2·2	— 6·0
2·8—4·4     "     "     ".....	5·5	3·6	6·3	— 2·9*
4·7—7·9     "     "     ".....	4·5	6·0	6·8	— 18·2

*Sources of the several Impurities in Sewer Air.*

The source of organic matter present in sewer air over and above that present in outside air at the time is of course the sewage itself. The organic matter arising from the sewage is most probably wholly or for the most part gaseous, for the conditions which cause the number of micro-organisms in sewer air to be less than in outside air would also affect any solid organic matter or dust in a similar manner, so that we should expect the solid organic matter in sewer air to be less than in outside air at the same time. The gaseous organic matter arising from the sewage itself will probably be of two kinds, that volatile *per se*, and that volatile with the aqueous vapour from the sewage water. Organic matter may also get into the air in cases where splashing occurs from the entry of a side drain high up in the wall of a sewer.

The carbonic acid in sewer air over and above that in outside air may have two sources. It may be due to diffusion into the sewer from the neighbouring soil; but probably its chief source is oxidation of organic matter in the sewage and the air of the sewer. Miller many years ago demonstrated the existence of such oxidation in the Thames, when it was the recipient of all the London sewage. He showed by a series of analyses of the gases dissolved in Thames water, collected at various points above and below London, that from Kingston to Greenwich the carbonic acid increased, while the oxygen rapidly diminished.

Two possibilities occur as to the source of the majority of the micro-organisms in sewer air. They may in the first place be derived from the sewage and sewer walls. If this were so to any great extent we should expect their numbers to increase with the

\* The irregularity here is due to the results in the Dock Street sewer, which was examined on a dry and windy day, when the micro-organisms in the outside air were very numerous, owing to dust, so that the difference between outside air and sewer air was very great (see the large table of results, p. 506). In the first classification one of the Dock Street analyses falls into each class, in the second classification two fall into the third class, leaving none in the second class. If the Dock Street analyses were left out, or if the third class began at 4·9 vols. of carbonic acid instead of at 4·7, the decrease in micro-organisms would run quite regularly.

length of time during which the air is present in the sewer, and therefore with increase in the carbonic acid. But it has been shown above (p. 509) that the very opposite is the case, the micro-organisms becoming less numerous with increase of carbonic acid. We have also classified the whole of our observations according to whether they were made at points where there was a strong, moderately strong, or very feeble draught. Here again it will be seen that the results are against the theory that the micro-organisms come from the sewer itself.

	Carbonic acid.	Organic matter.	Micro-organisms.
Strong draught .....	6·6	5·7	9·9
Moderate draught.....	7·5	8·8	8·9
Little or no draught.....	9·4	8·1	6·7

	In excess of outside air.		
	Carbonic acid.	Organic matter.	Micro-organisms.
Strong draught .....	2·6	3·5	— 2·3
Moderate draught.....	3·9	6·6	— 9·2
Little or no draught.....	6·0	5·5	—14·3

A similar result was obtained from our observations at Westminster, where we made six observations before, and six after the improvements in the ventilation referred to above.

	Carbonic acid.	Organic matter.	Micro-organisms.
Average before improvement.....	7·8	11·0	7
Average after improvement.....	6·2	2·7	10·3

The only other source for the micro-organisms of sewer air is contamination from the outside air. The same arguments which have just been applied against the sewer itself being a source of micro-organisms may be urged in favour of their origin from outside air.

The mere fact that the average number found in the sewer air (8·9) was less than that in outside air at the same time (15·9) is itself a strong argument in favour of the origin of most of the micro-organisms from outside air. If the air takes up micro-organisms in its course along a sewer, we should expect the number to increase rather than diminish during its passage, whereas the opposite is the case, doubtless from gradual settling of solid particles. This settling is perhaps even greater than appears from our analyses, as it was not practicable to take specimens of outside air at the gratings in the centre of the roadway with the traffic proceeding as usual. At these points the contamination of the air by solid particles of organic origin would of course be at its maximum.

It will be noticed that in the analyses made at Westminster the numbers obtained for the sewer air close to the Clock Tower were always larger than those for outside air (see Table, pp. 504—505). Not much stress can, however, be laid on this fact, as a great part of the air passing along the sewer at this point came from a side drain near the Clock Tower, leading from a point where the outside air was much more likely to be contaminated by dust from traffic than in the central court, where the outside air analyses were made. The outside air determinations at Westminster apply strictly to the sewer determinations near the Victoria Tower and kitchen, as these determinations were made just at the opening of the inlet grating ventilating this part of the sewer. It will be seen that the micro-organisms inside the sewer decreased in proportion to the decrease in those present in the outside air.

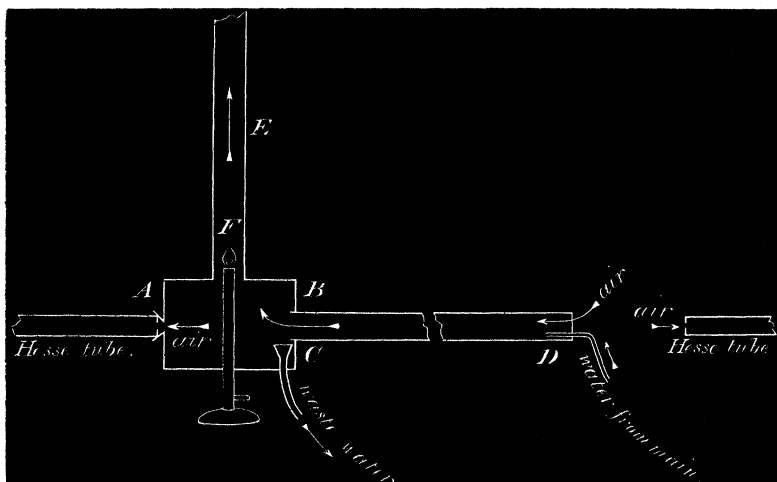
Another argument in favour of the origin of most of the micro-organisms from outside may be derived from the fact that the average proportion of moulds to bacteria was nearly the same in the sewer air and corresponding outside air, 1 to 9 in the former and 1 to 8 in the latter. Were the micro-organisms in sewer air mostly derived from a different source than outside air we should expect the proportion to be different. Thus in two cases referred to below, in which the micro-organisms were evidently derived from splashing in the sewer, among 128 micro-organisms there were no moulds. In the micro-organisms present in the air of naturally ventilated schools and one-roomed houses, the average proportion present was found to be 1 : 132 and 1 : 49 respectively, as against 1 : 2·5 in the corresponding outside air ('Phil. Trans.' 1887, B, p. 99).

A final argument is that so far as a naked-eye examination of the colonies allowed one to judge, the micro-organisms in the sewer air we examined were, with perhaps one exception, similar to those in outside air. The exception referred to was in the case of some very rapidly liquefying colonies which occurred in several samples of sewer air, collected at points where there was more or less splashing.

These possibly came from the sewer itself, as we have not observed in outside air or in buildings any colonies which liquefied the jelly as rapidly or so extensively.

The conclusion thus arrived at as to the source of most of the micro-organisms present in sewer air is, perhaps, at first sight, contrary to what one might have expected. It is in agreement with the fact that the state of cleanliness or filthiness of a sewer seems to have no perceptible effect on the number of micro-organisms present in the air of the sewer. Thus two observations on two different days and at two different points of the dirtiest sewer we examined, gave only  $2\frac{1}{2}$  and 12 micro-organisms respectively, as compared with an average of  $4\frac{1}{2}$  and 9 in other and cleaner sewers on the same days. Our conclusion is also in agreement with what is known as to the distribution of bacteria in air. Nägeli ('Die Niederen Pilze,' pp. 109, 111) has shown that liquids or damp substances do not, with ordinary air currents, give off micro-organisms to the surrounding air. He even found that air drawn through gravel which had been saturated with filth and then dried, gave off no micro-organisms (p. 169). Miquel ('Comptes Rendus,' vol. 91, p. 64) states that the vapour of water rising from the soil, from rivers, or from masses in full putrefaction, is free from germs; that the gases evolved from decaying substances, and the air passed over putrid meat are free from germs, provided that the putrefying substance is as moist as soil taken 0.3 metre from the surface. The experiments of Professor Frankland ('Roy. Soc. Proc.,' vol. 25, 1877, p. 542) also point to the improbability of micro-organisms being disseminated in air by such agitation of a liquid as that produced by the flow of sewage along a sewer. On the other hand, it is well known that the micro-organisms already present in air are always tending to sink to the ground. On this fact Hesse's method depends. Hence air in its passage along a sewer will presumably tend to gradually deposit its micro-organisms, especially if the air-current is slow.

In order further to elucidate this point, and in particular with regard to the drain pipes leading into houses, we made some experiments with an artificial drain-pipe. Through the side of a wooden box, AB, there was passed the end of a piece of glass tubing, CD, 5 feet long and  $1\frac{3}{4}$  inches in diameter, and open at both ends. In the opposite side of the box there was a hole, by means of which the air inside the box could be connected with the entrance to a Hesse's tube, and the micro-organisms thus determined. Through the roof of the box there passed a chimney, in which a draught was maintained by means of a small flame, F, kept burning at the bottom. This, of course, caused a corresponding draught through the long tube and into the box. A constant stream of water was kept running along the



bottom of the experimental sewer, the sides of which were also moistened before each experiment. By estimating the micro-organisms in the air at the mouth of the tube and in the box, the difference caused by passage of the air along the tube could be determined. The rate of the current of air through the long tube was in all the experiments 5 feet in six seconds. The determinations were made simultaneously, after the draught had been established for a short time.

No. of experiment.	Quantity of air aspirated through Hesse's tube.	Air of laboratory (before passing through tube).		Air of box (after passing through tube).	
		Total micro-organisms.	Moulds.	Total micro-organisms.	Moulds.
1. ....	$\frac{1}{2}$ litre ....	200	..	100	..
2. ....	$\frac{1}{2}$ litre ....	205	..	141	..
3. ....	5 litres ....	4	0	3	1
4. ....	5 litres ....	9	0	2	1
5. ....	5 litres ....	1	1	1	0
6. ....	$\frac{1}{2}$ litre ....	344	47	139	42
7. ....	$\frac{1}{2}$ litre ....	221	67	175	73
	Average =	141	23	80	23

In Nos. 1, 2, 6, and 7 the air was rendered dusty by shaking mats in the room. Nos. 3, 4, and 5 were made with the air of the laboratory in its ordinary condition.

It will be seen that the micro-organisms were diminished by nearly one half in passing along the tube. This confirms our conclusions as to the settling of micro-organisms in sewer gas. The micro-organisms would settle out of a drain-pipe especially with great rapidity. Judging from the rate at which they settle in a Hesse's tube, air standing in, or passing along, a 4-inch drain-pipe would become entirely free of micro-organisms within three or four minutes. Hence it seems improbable that micro-organisms can penetrate into a house from a sewer unless with a pretty rapid current towards the house.

It will be seen from the table that the moulds are more numerous in proportion to bacteria after the air has passed through the tube than before. This is due to the fact, first observed by Hesse, that moulds fall through air less rapidly than bacteria. We should expect to find a similar alteration in the proportion in badly ventilated sewers, but our observations in such sewers were not sufficiently numerous to enable us to say whether this is actually the case.

Although, as has been seen, most of the micro-organisms present in the air of the sewers we examined seem to have come from the outside air, yet in some cases we had distinct evidence of the dissemination of micro-organisms from sewage itself. In Dundee a few, and at Westminster a large proportion of the drains were found to enter the sewers through the roof. This gave rise to a considerable amount of splashing, the effect of which on the dissemination of micro-organisms in the air it seemed of great importance to investigate. The following observations in the sewers bear upon this point. An analysis was made within about 2 feet of a shower of water proceeding from the roof of the Dock Street sewer, the draught being very slight. The number of micro-organisms present was 103 (all bacteria). An analysis made shortly afterwards a few feet to windward of the shower of water gave only twelve micro-organisms. During one of the analyses made at Westminster, a sudden and very violent shower of sewage occurred about 10 feet to windward of the tripod carrying the Hesse's tube. In this case the number found was 25 (all bacteria), whereas an analysis made at the same point a few minutes later, after the dripping had ceased, gave only eight micro-organisms. One of the analyses in the Murraygate sewer was made within about 30 feet of the point where the Hill Town sewer enters the Murraygate sewer, there being a draught of about 2 feet per second from this point to the spot where the analysis was made. The Hill Town sewer has a steep incline, and the water contained in it rushes down with great force, forming a sort of water-fall, the roar of which sounded most impressive as it echoed along the sewer. The analysis only gave three micro-organisms per litre.\*

\* The low number thus obtained was possibly owing to the fact that the waste

From the first two observations it appears that micro-organisms are undoubtedly disseminated in sewer air by splashing; but whether they are carried far in the air cannot be decided from the above experiments. The point is one of great practical importance, as the micro-organisms in question are those on which most suspicion of properties injurious to health naturally falls. Hence we thought it desirable to make some laboratory experiments with a view to elucidating the matter.

In connexion with the effects of splashing we also investigated the effects of the bursting of bubbles. Professor Frankland ('Roy. Soc. Proc.,' vol. 25, p. 542) has already made experiments on this point by means of lithia solutions. He found that lithia was disseminated in the air and carried to a considerable distance, when a solution of lithia was made to effervesce. Hence the presumption is that micro-organisms might be disseminated in a similar way.

Our experiments were made with the artificial drain-pipe arrangement described above (pp. 513—514). Control determinations of the air in the box were first made after the draught had been established some little time. A putrefying solution was then poured from a height into a vessel placed at about 6 inches below the end of the glass tube, so as to imitate the splashing in a sewer; or effervescence was brought about in the same solution, placed at the mouth of the long glass tube by adding sodium carbonate and hydrochloric acid, or by blowing small and numerous jets of air through the putrid fluid by means of a fine rose from an ordinary garden hose pipe.

water from a dye works was discharged into this sewer, accompanied by a distinct smell of chlorine at the time of our experiment. These conditions possibly exerted a disinfecting action.



No. of experiment.	Mode of producing splashing or effervescence.	Quantity of air aspirated.	Air of box after passing through drain-pipe.		Remarks.
			Without splashing, &c.	During splashing, &c.	
Series I.					
1.....	By addition of hydrochloric acid and sodium carbonate to putrid fluid.	900 c.c.	0	2	The lowness of the numbers obtained during effervescence in this case was possibly due to the disinfecting action of free hydrochloric acid. There were no moulds in either case.
2.....	Ditto.....	900 c.c.	0	4	
Series II.					
3.....	By pouring putrid matter from a height.	1 litre.	1	About 370	On second day, after which they were too numerous to be counted. On the 5th day 300 moulds were counted, but the bacteria were too numerous. Ditto. About 100 moulds on 5th day.
4.....	Ditto.....	1 litre.	1	About 380	
Series III.					
5.....	By blowing air through putrid fluid.	1 litre.	1	About 600	Ditto. About 100 moulds on 5th day.
6.....	Ditto.....	1 litre.	1	About 500	Ditto. About 143 moulds on 5th day, one being like the large ones in 7th experiment.

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No. of experiment.	Mode of producing splashing or effervescence.	Quantity of air aspirated.	Air collected directly over and about 9 inches above the putrid matter.		Remarks.
			Without splashing, &c.	During splashing, &c.	
Series IV. 7.....	By pouring putrid matter from a height.	1 litre.	0	About 380	On 2nd day, after which they were too numerous to be counted. On 5th day there were 38 mounds, of which six were large beautiful white interlacing colonies, throwing up delicate hair-like threads, about an inch long, and bearing minute black fruit heads at their extremities.

These results are very decided, and confirm and extend for micro-organisms the results obtained by Professor Frankland for lithia solutions. They show conclusively not only that micro-organisms are disseminated in sewer air by splashing, but that those having this origin may be carried to a considerable distance along a sewer or drain-pipe. Calculating from these experiments, air vitiated as above described, and to a similar extent, would still contain about 400 micro-organisms per litre after travelling about 60 yards, in a sewer 5 feet high, and with a draught of about 1 foot per second. It is therefore of the greatest importance that sewers and drains should be so arranged as to avoid splashing as much as possible.

*The Physiological Effects of Unorganised Organic Matter in Sewer Air.*

In view of the fact that ordinary sewer air, in the absence of splashing, turned out to be to all appearances comparatively innocent as regards its micro-organisms, and assuming that it has an injurious effect on health, we directed further attention to the unorganised organic matter present in it. Of organic compounds most likely to produce some of the bad effects ascribed to sewer air, volatile ptomaines\* at once suggest themselves, on account of the intensely poisonous properties possessed by various known ptomaines.† We therefore endeavoured to ascertain whether sewer air contains any poisonous volatile bases. For this purpose air was drawn continuously for thirty-four days from the sewer side, below the trap, of an earthen pipe, which acted as the drain from the College water-closets and urinals. This air was bubbled continuously through very dilute sulphuric acid, in order that any basic substance which the air contained might be retained. The solution thus obtained was subsequently neutralised exactly with ammonia, and evaporated to dryness on a water-bath. The residue was dissolved and injected subcutaneously into rabbits, but produced no effect whatever, even in doses of a gram of the dry substance. Evidently if there was any poisonous substance in the air, it was not contained in the residue injected. Unfortunately this experiment is not conclusive, on account of the instability of many of the organic bases in question.

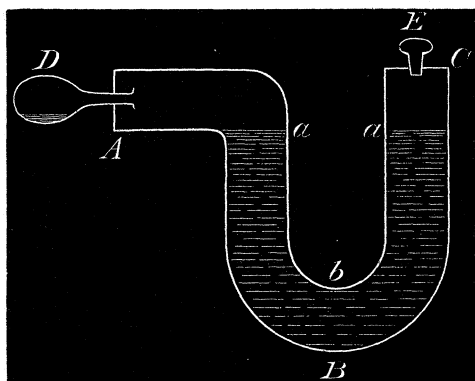
If poisonous organic substances had been present in serious quantities in the air of the sewers we examined, we should presumably have ourselves felt some effects from them, as we were sometimes in the sewers for several hours, more or less continuously. We could never observe any bad effects, however, from our stay, although we were previously quite unaccustomed to entering sewers.

\* Ptomaines are basic nitrogenous compounds formed by the decomposition of animal or vegetable matter.

† Cf. Brieger, 'Ueber Ptomaine,' 1885-86.

*Experiments on the Efficiency of Water-traps.*

The means commonly employed for preventing the escape of sewer air into houses is the ordinary water-trap. Since the experiments of Nægeli ('Die Niederen Pilze,' p. 109) it has been known that these traps, when acting properly, absolutely prevent the passage of micro-organisms. But it is evident that they cannot altogether prevent the passage of volatile constituents of sewer air, and we thought it worth while to make a few experiments on this point. We were not aware that the matter had already been experimentally investigated by Fergus ('The Sewage Question,' 1874), who employed methods similar to those used by us. As, however, the test substances used by us were nearly all different from those employed by Fergus, it may be well to give the results of our experiments. A leaden U-shaped trap, A, B, C,  $2\frac{3}{4}$  inches in diameter, and with a seal, *a b*, of 3 inches in depth, was closed at each end, A and C, with a sheet of india-rubber stretched tightly over the mouth and fixed with wire, each sheet



being perforated by a hole in the middle. The trap was then filled with water, and a glass stopper placed in the aperture E, while the neck of a flask D, containing the substance under investigation, was fixed through the india-rubber sheet at A. The whole was then left at rest, and observations made from time to time by removing the stopper and ascertaining whether the smell of the substance in D could be detected at E. In other cases a tightly fitting inverted test-tube, containing litmus or other test-paper, was inserted at E, in place of the glass stopper, and observations made as to when the test-paper was first distinctly affected. The results obtained are given in the following table:—

Substance in Flask D.	Test used for detection.	Depth of seal.	Vol. of water in trap.	Time required by vapour to pass from D to E.	Remarks.
Oil of mustard.....	Smell.....	3 inches.	890 c.c.	5½—5¾ hours.	In leaden trap.
Oil of garlic.....	" .....	3 "	930 "	5¼—8 hours.	Ditto.
Oil of mint.....	" .....	3 "	910 "	5¼—5½ hours.	Ditto.
Calcium phosphide.....	Silvernitrate paper and smell.	3 "	820 "	5¼—7½ hours.	Ditto.
Putrid meat juice.....	Smell.....	3 "	960 "	About 4 days.	Water very milky after the experiment, and gave only a slight reaction for lead.
Ammonium sulphide.....	Lead acetate paper and smell.	3 "	950 "	Could not be detected even after 10 days.	In leaden trap : H <sub>2</sub> S probably taken up by lead or oxidised.
Ditto.....	Ditto.....	¼-inch.	90 "	7½—33 hours.	In earthenware trap.
Ammonium carbonate.....	Red litmus paper.	3 inches.	930 "	50—55 hours.	In leaden trap.
Hydrochloric acid (strong) .	Blue litmus paper.	3 "	770 "	Could not be detected even after 10 days.	In leaden trap.

Fergus found that free ammonia came through a somewhat similar trap in 15 minutes, carbonic acid in  $1\frac{1}{2}$  hour, sulphuretted hydrogen in 3 to 4 hours, &c. He also refers to similar experiments in which a ventilating pipe was placed between the substance experimented on and the trap, in which the result was much the same, except that the time occupied in penetrating the trap was longer.

Though it is thus the case that water-traps after some time allow a certain amount of various volatile substances to pass through, yet it is hardly conceivable that the small amount thus allowed to pass can have any appreciable influence on health.

We do not propose to enter here on any general discussion of the effects of the inhalation of sewer air on health. The results of the foregoing investigations are clearly such as to make us much more suspicious as to supposed evidence of the bad effects of ordinary sewer air, such as that of the sewers examined by us. At any rate it is evident that "sewer gas," unless it has been vitiated by splashing, has a much less deadly composition than is often supposed. It must be remembered, however, that the matter cannot in the present state of our knowledge be settled by analyses alone, though analyses may serve as a guide in the investigation.

